New Small Satellite Capabilities for Microwave Atmospheric Remote Sensing: The Earth Observing Nanosatellite-Microwave (EON-MW)

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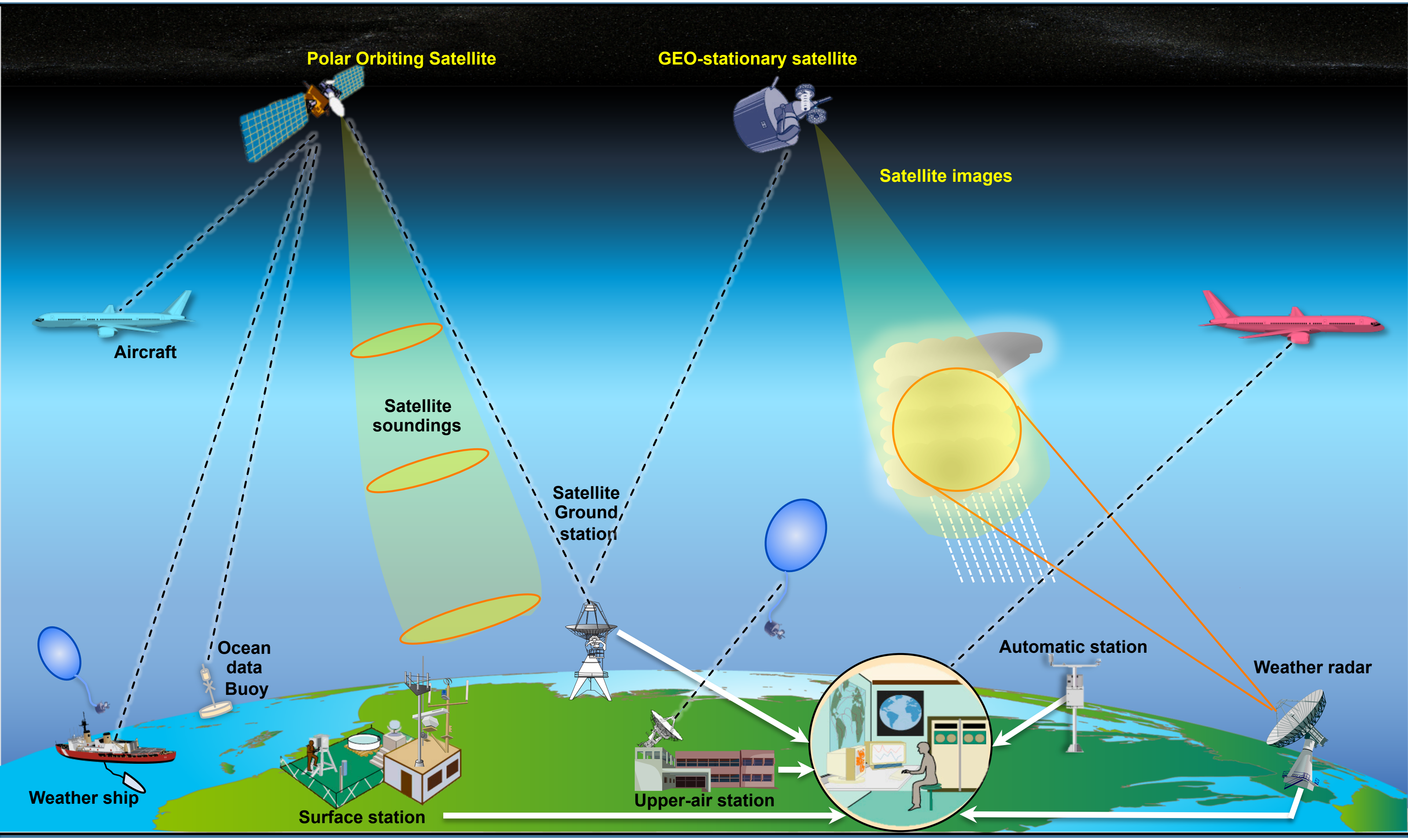
Outline

- Introduction and Motivation
- Foundational Work: MicroMAS-1, MicroMAS-2, and MiRaTA
- The Next Step: EON-MW
- Summary

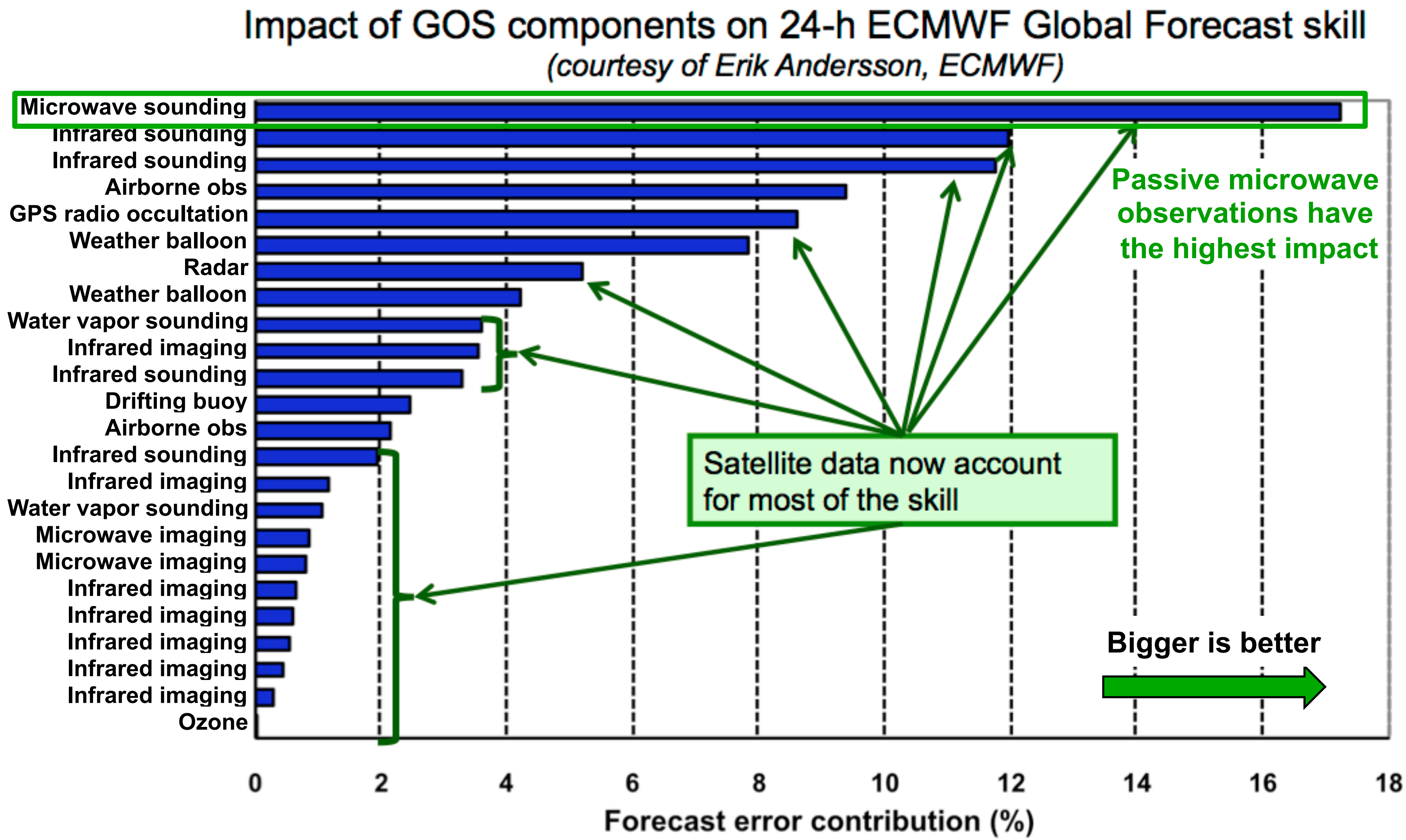
MicroMAS = Microsized Microwave Atmospheric Satellite
MiRaTA = Microwave Radiometer Technology Acceleration
EON-MW = Earth Observing Nanosatellite-MicroWave

Global Observing System (GOS) For Environmental Monitoring



Source: World Meteorological Organization

Satellites Provide the Most Forecast Skill



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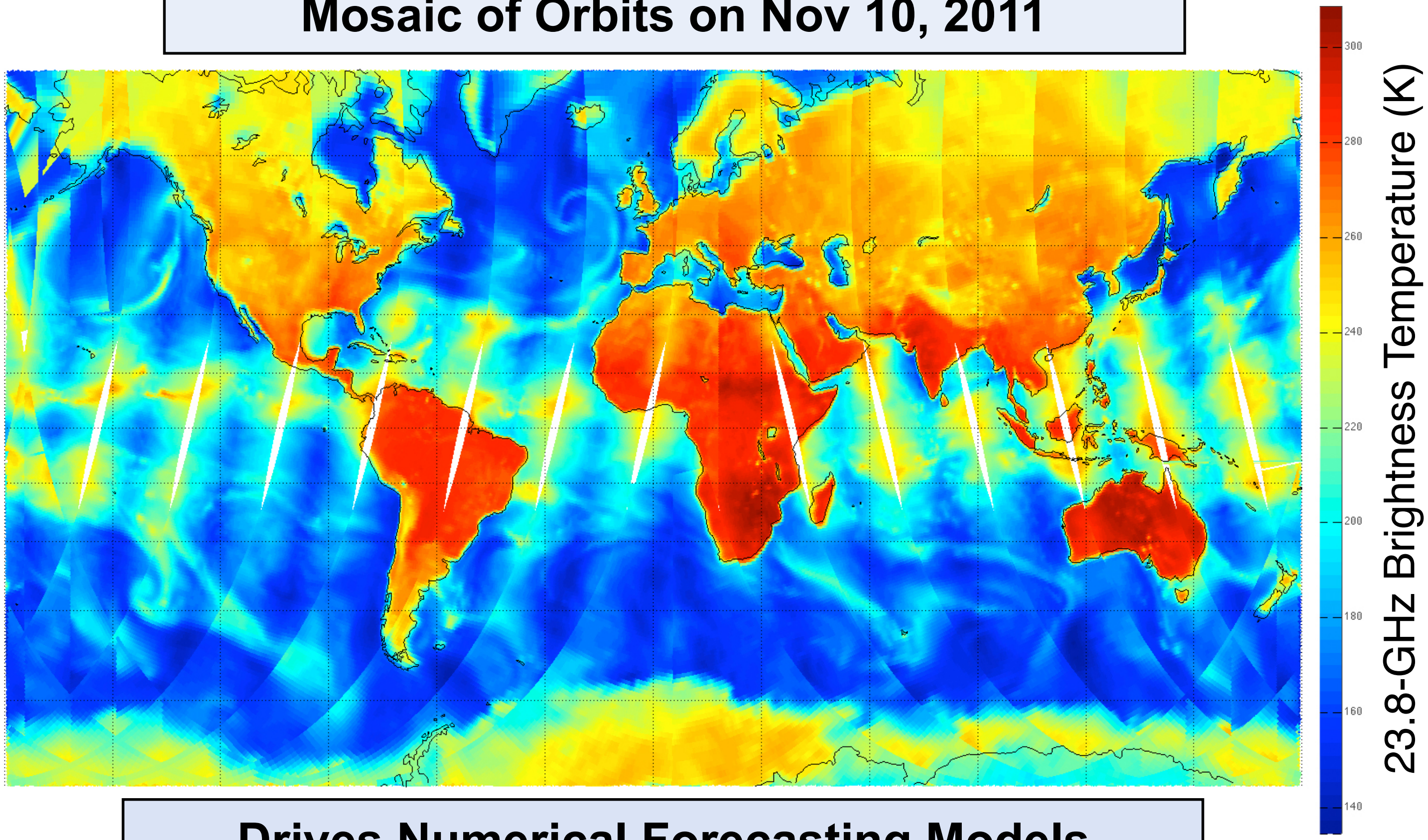
Need: All-Weather, High-Resolution, Persistent 3-D Observations of the Earth's Atmosphere

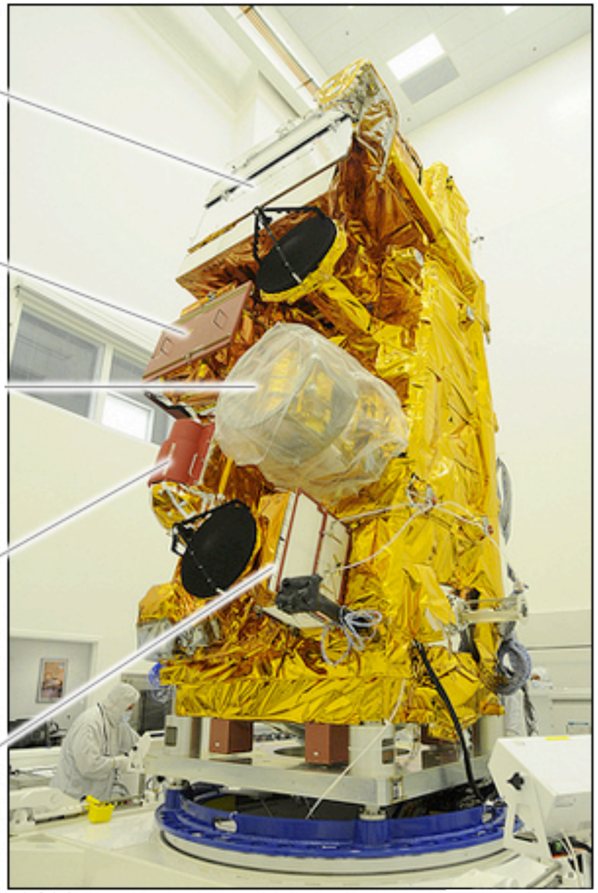
Advanced Technology Microwave Sounder
Mosaic of Orbits on Nov 10, 2011



Drives Numerical Forecasting Models
Monitoring of Severe Weather and Hurricanes
Hydrologic and Climate Studies

Traditional Approach: Big Satellites

Suomi NPP Satellite
(Launched Oct 2011)



2100 kg **NASA/GSFC**

NPP: National Polar-orbiting Partnership

Current Approaches Unsustainable

- **Expensive**
- **Long development cycles**
- **Very high failure impact**

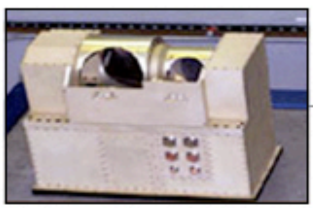
Independent Assessment

dependent ssessment

ependent sessment

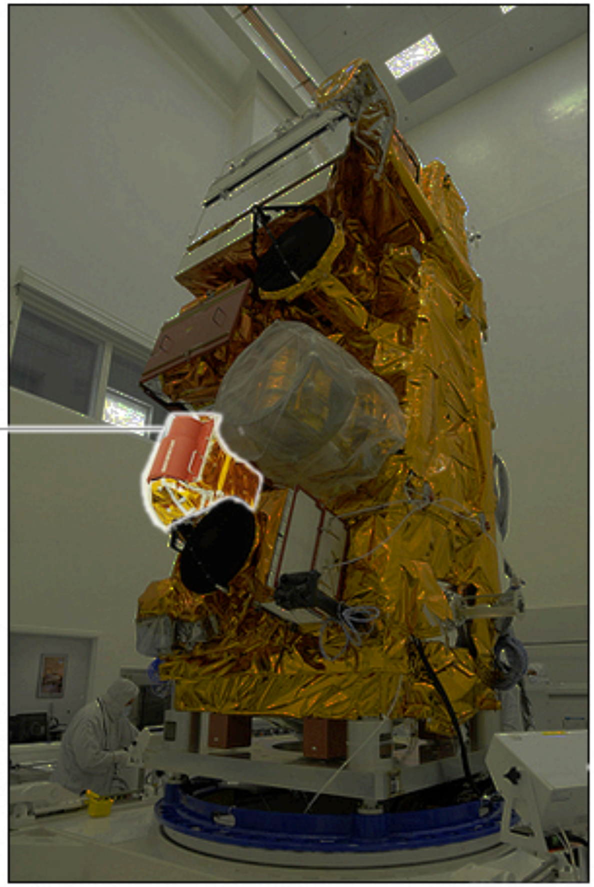
Focus: Microwave Sounding

Advanced Technology Microwave Sounder (ATMS)



100 kg, 100 W

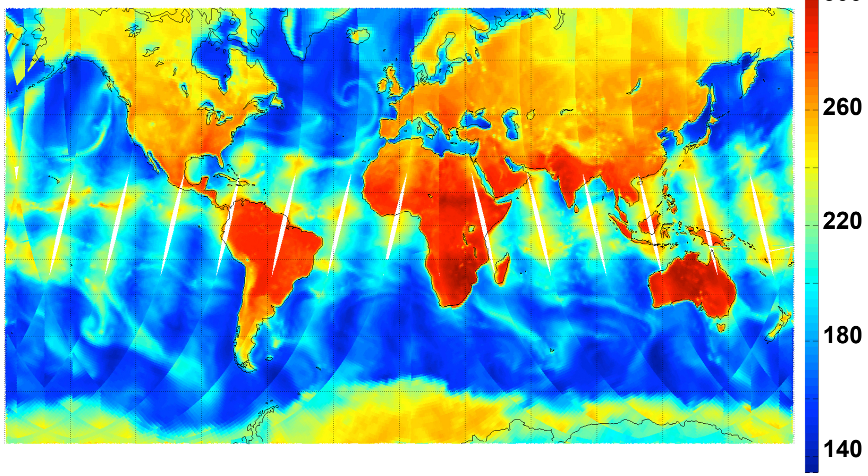
Suomi NPP Satellite (Launched Oct 2011)



2100 kg NASA/GSFC

NPP: National Polar-orbiting Partnership

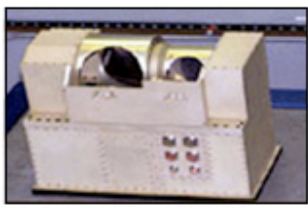
23.8-GHz Brightness Temperature (K)



- Microwave sensor amenable to miniaturization (10 cm aperture)
- Broad footprints (~50 km)
- Modest pointing requirements
- Relatively low data rate

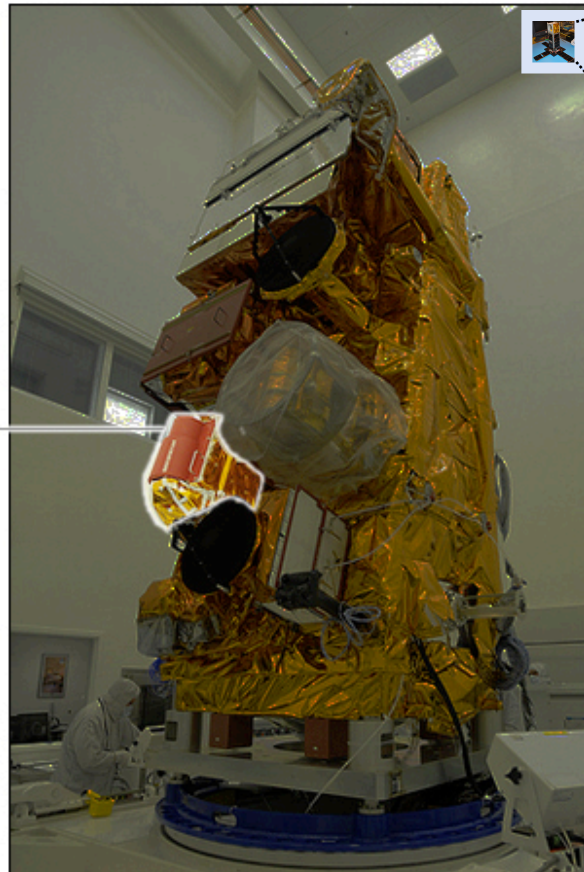
New Approach for Microwave Sounding

Advanced Technology Microwave Sounder (ATMS)



100 kg, 100 W

Suomi NPP Satellite
(Launched Oct 2011)

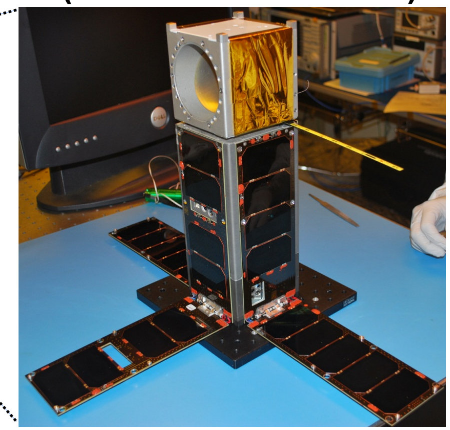


2100 kg

NASA/GSFC

NPP: National Polar-orbiting Partnership

MicroMAS Satellite
(Launched Jul 2014)



4.2 kg, 10 W, 34 x 10 x 10 cm

- Microwave sensor amenable to miniaturization (10 cm aperture)
- Broad footprints (~50 km)
- Modest pointing requirements
- Relatively low data rate

Perfect fit for a cubesat!

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MicroMAS-1, MicroMAS-2, and MiRaTA

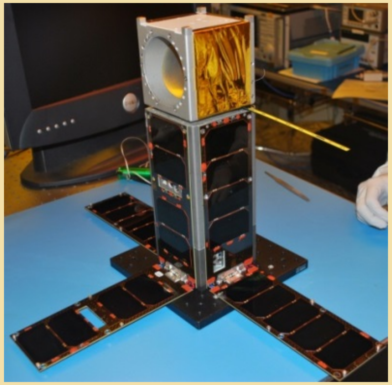
MicroMAS = Microsized Microwave Atmospheric Satellite
MiRaTA = Microwave Radiometer Technology Acceleration

MicroMAS-1

3U cubesat with 118-GHz radiometer

8 channels for temperature measurements

July 2014 launch, March 2015 release; validation of spacecraft systems; eventual transmitter failure

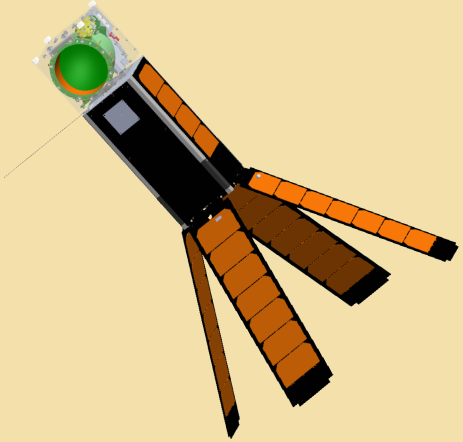


MicroMAS-2

3U cubesat scanning radiometer with channels near 90, 118, 183, and 206 GHz

12 channels for moisture and temperature profiling and precipitation imaging

Two launches in 2016

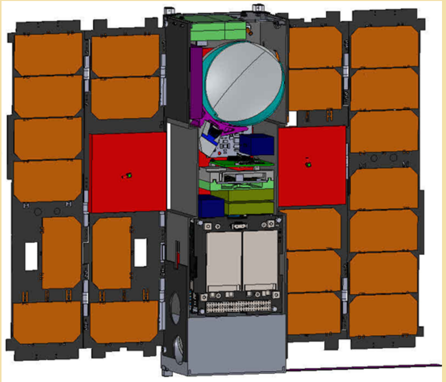


MiRaTA

3U cubesat with 60, 183, and 206 GHz radiometers and GPS radio occultation

10 channels for temperature, moisture, and cloud ice measurements

Nov 2016 launch on JPSS-1



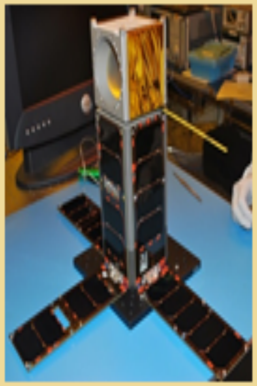
Earth Observing "Nanosatellite" (EON-MW)

MicroMAS-1

3U cubesat with 118-GHz radiometer

8 channels for temperature measurements

July 2014 launch, March 2015 release; validation of spacecraft systems; eventual transmitter failure



MicroMAS-2

3U cubesat scanning radiometer with channels near 90, 118, 183, and 206 GHz

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Two launches in 2016

MiRaTA

3U cubesat with 60, 183, and 206 GHz radiometers and GPS radio occultation

10 channels for temperature, moisture, and cloud ice measurements

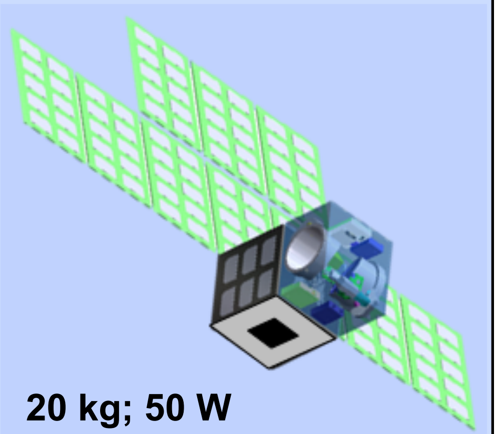
Nov 2016 launch

EON-MW

12U satellite with 22 channels to replicate ATMS

High-performance, radiation tolerant design; >two-year mission life

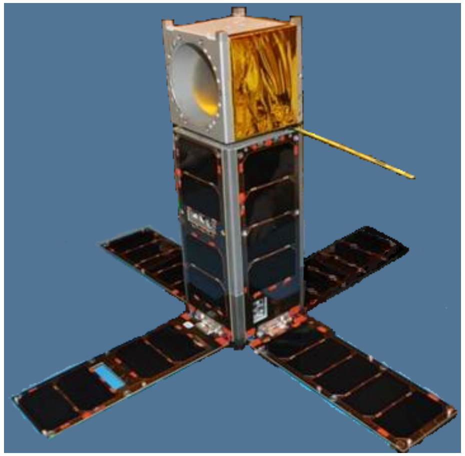
2018/2019 launch



20 kg; 50 W

Successful MicroMAS Release
March 4, 2015

Micro-sized Microwave Atmospheric Satellite
(Released from ISS 3/4/2015)

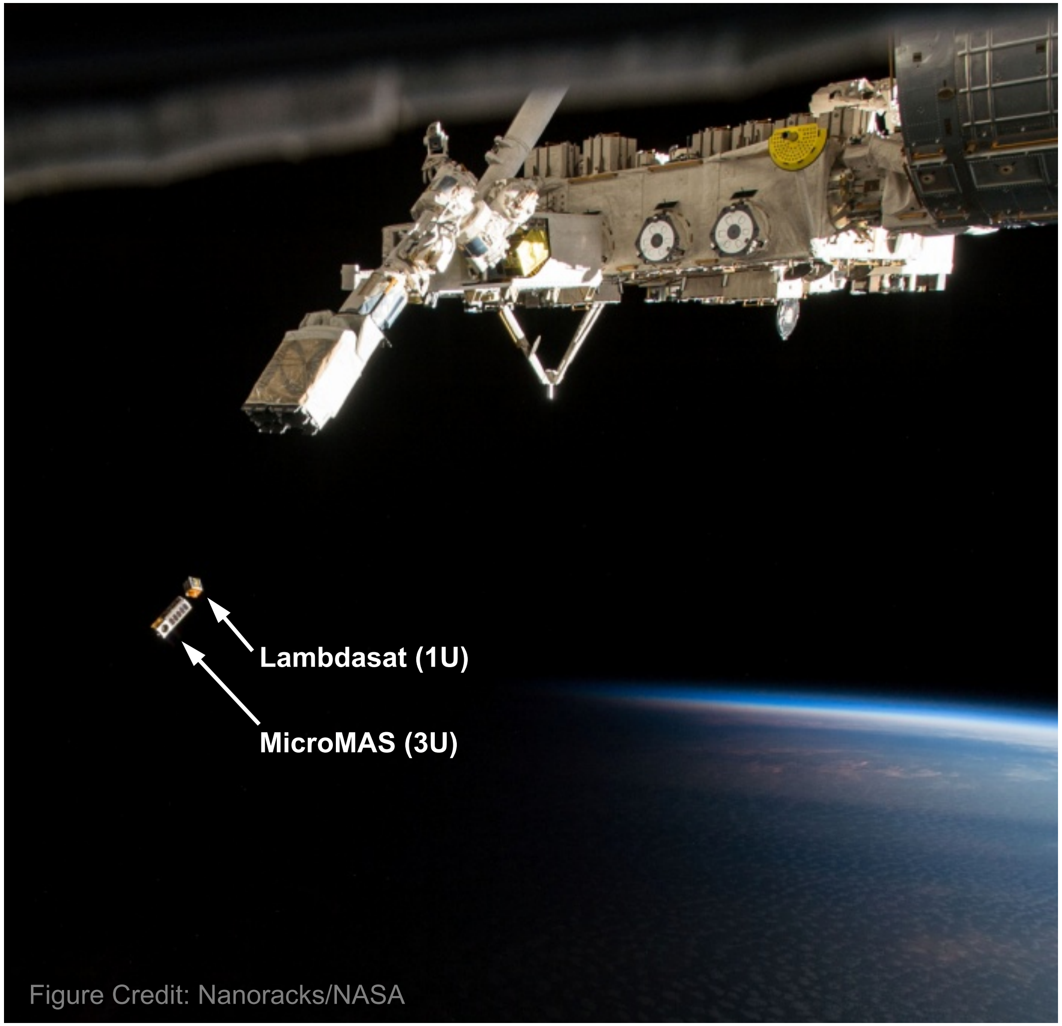


4.2 kg, 10 W, 3U (34 × 10 × 10 cm)

MicroMAS provides high-resolution radiometric imagery for improved weather forecasting

Collaborative mission between MIT LL and MIT Campus (Aero/Astro)

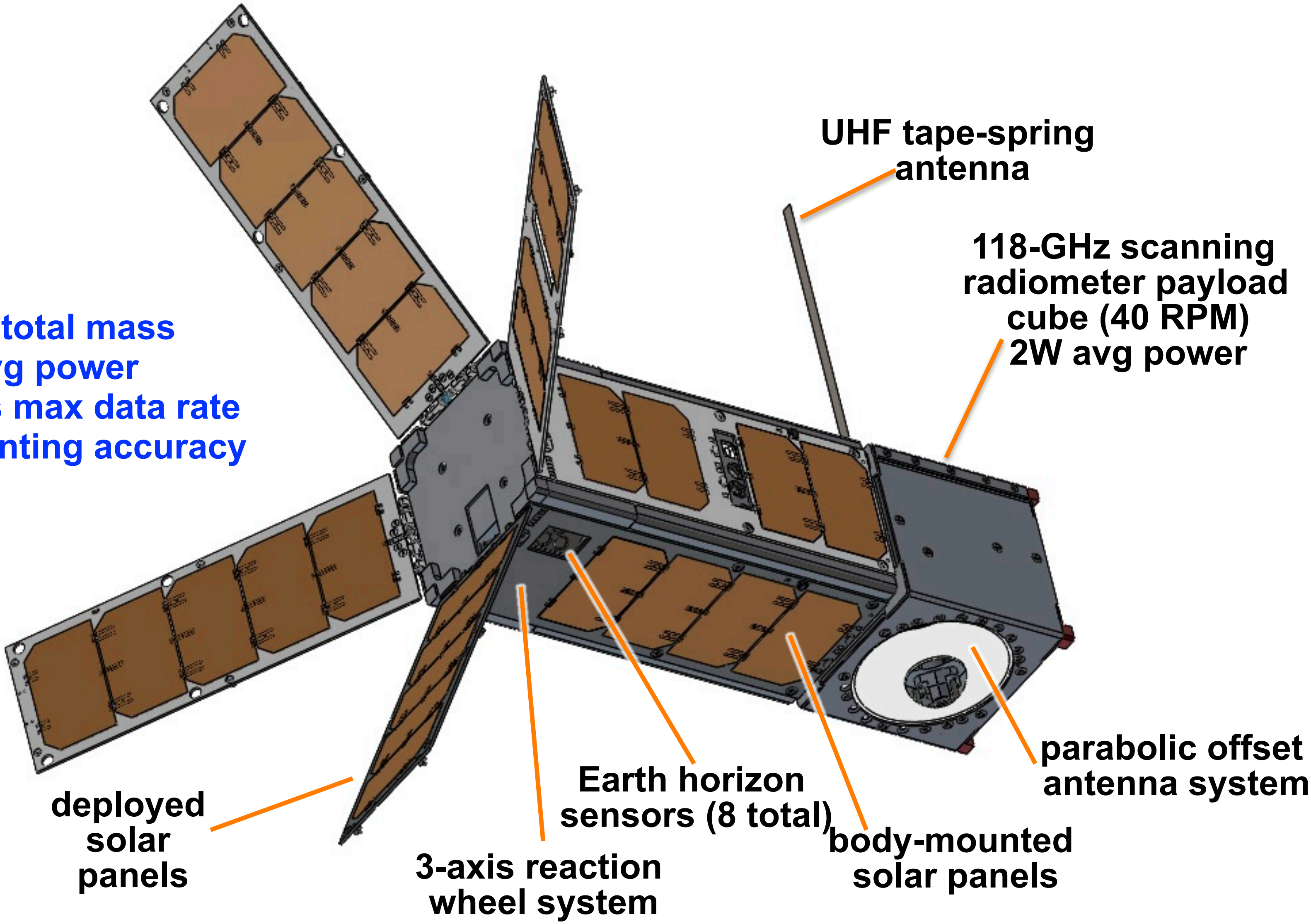
- **MIT Campus: Spacecraft bus**
- **MIT LL: Payload and system I&T**



MicroMAS transmitter fault occurred two weeks into mission.
No payload data downloaded to date.

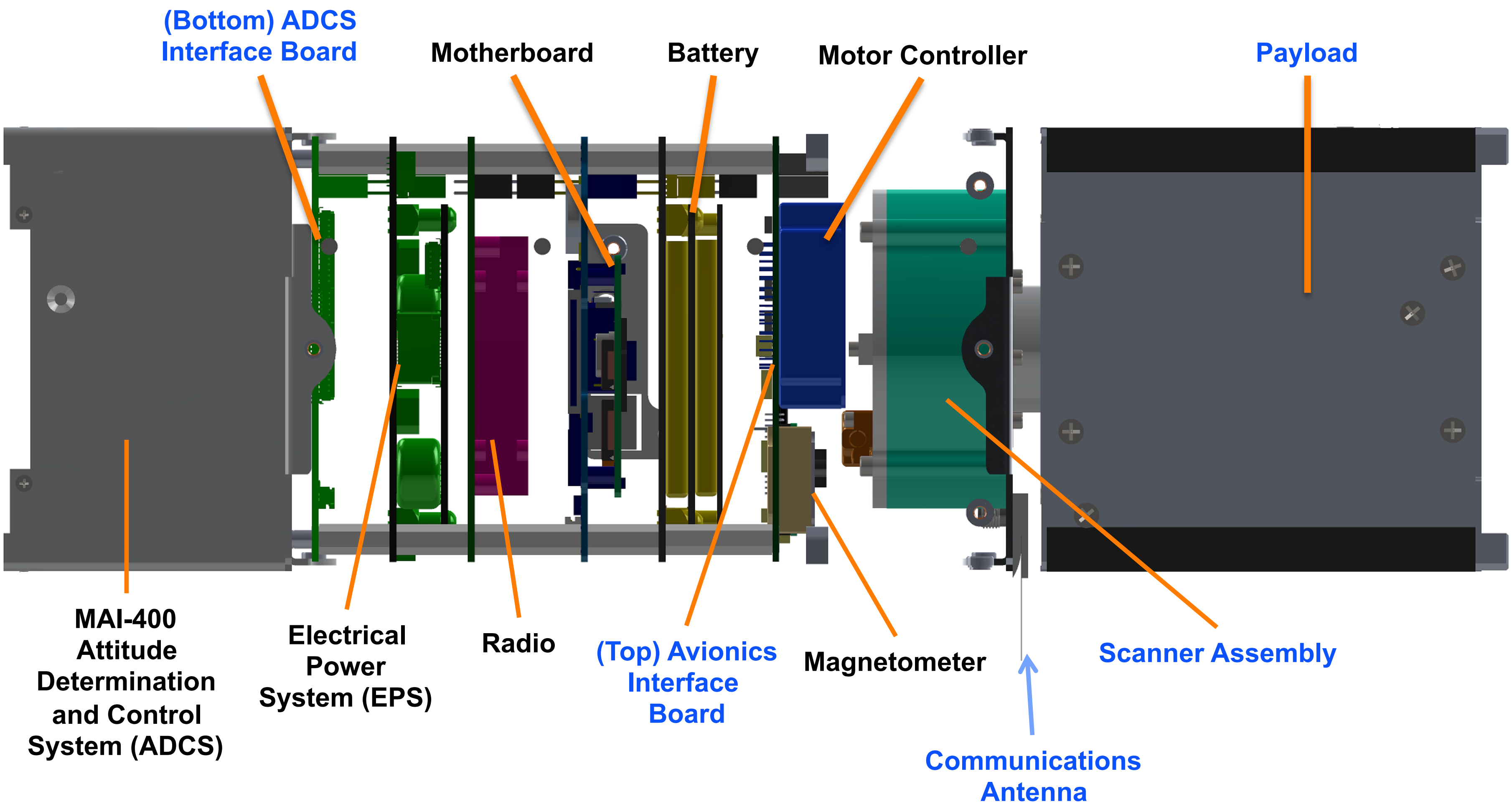
The MicroMAS CubeSat

- 4.25 kg total mass
- 10 W avg power
- 16 kbps max data rate
- 0.5° pointing accuracy



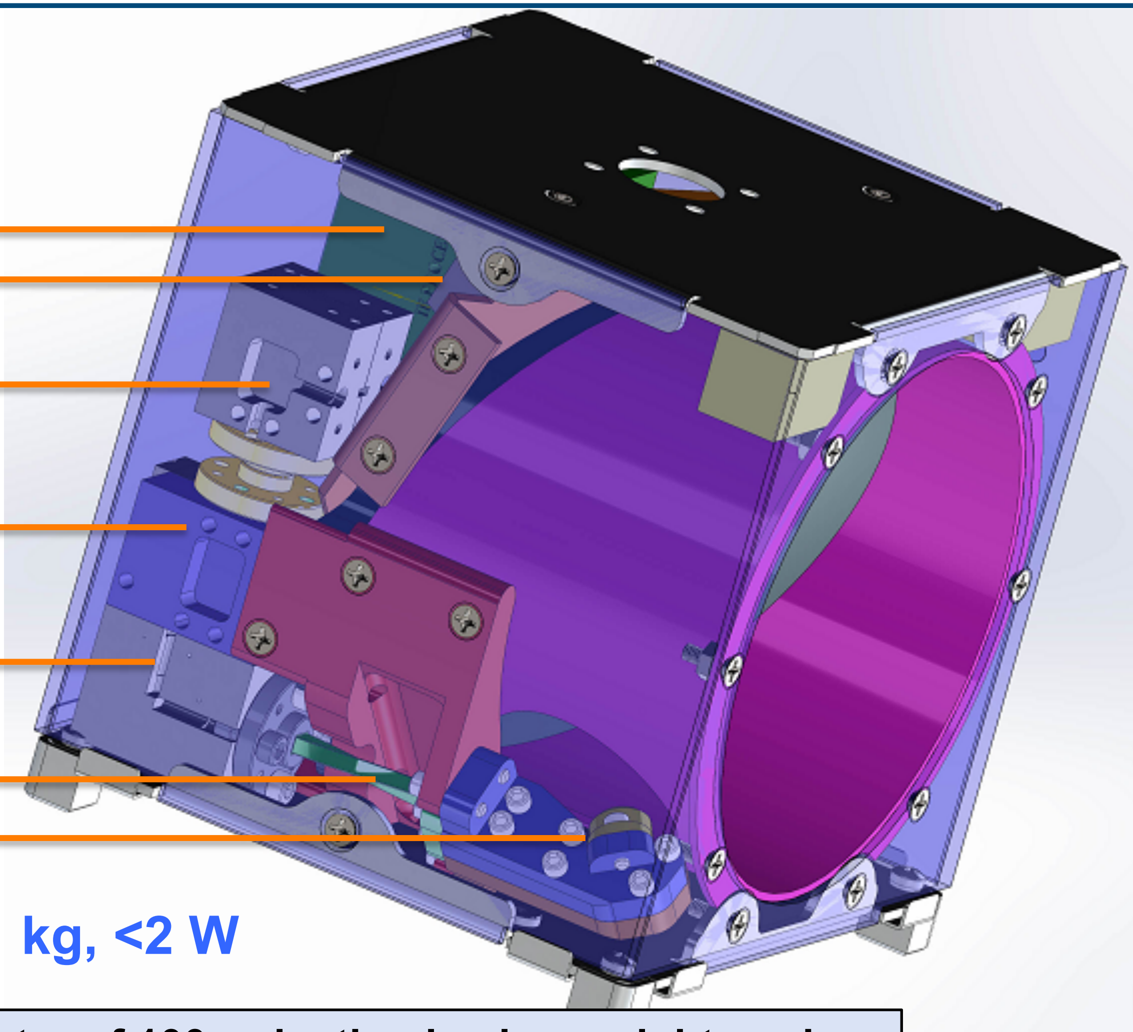
MicroMAS Bus Design

Custom vs. COTS Parts



Timely development of COTS parts was a major program challenge

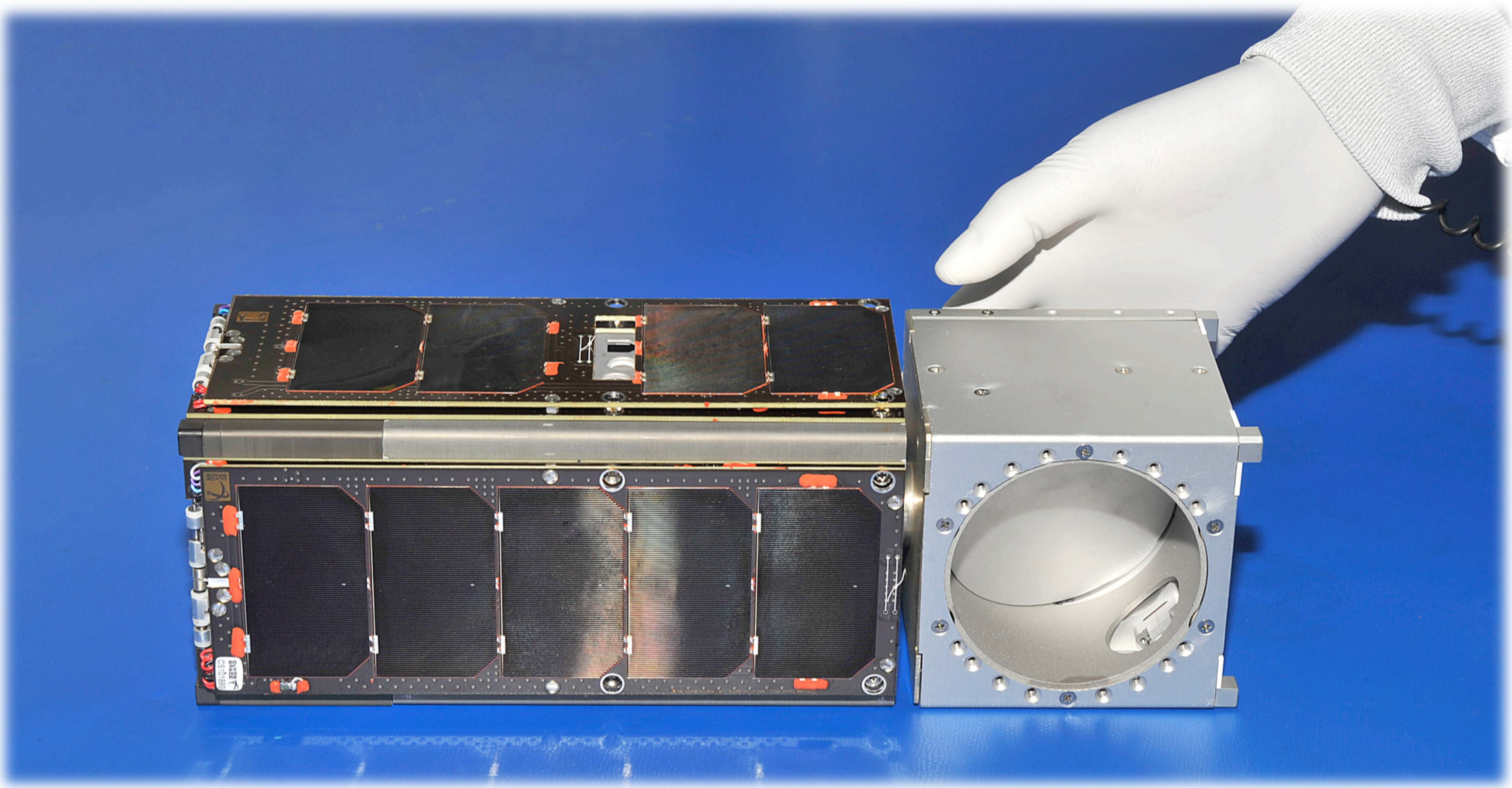
MicroMAS Payload (Side View)
118-GHz Spectrometer



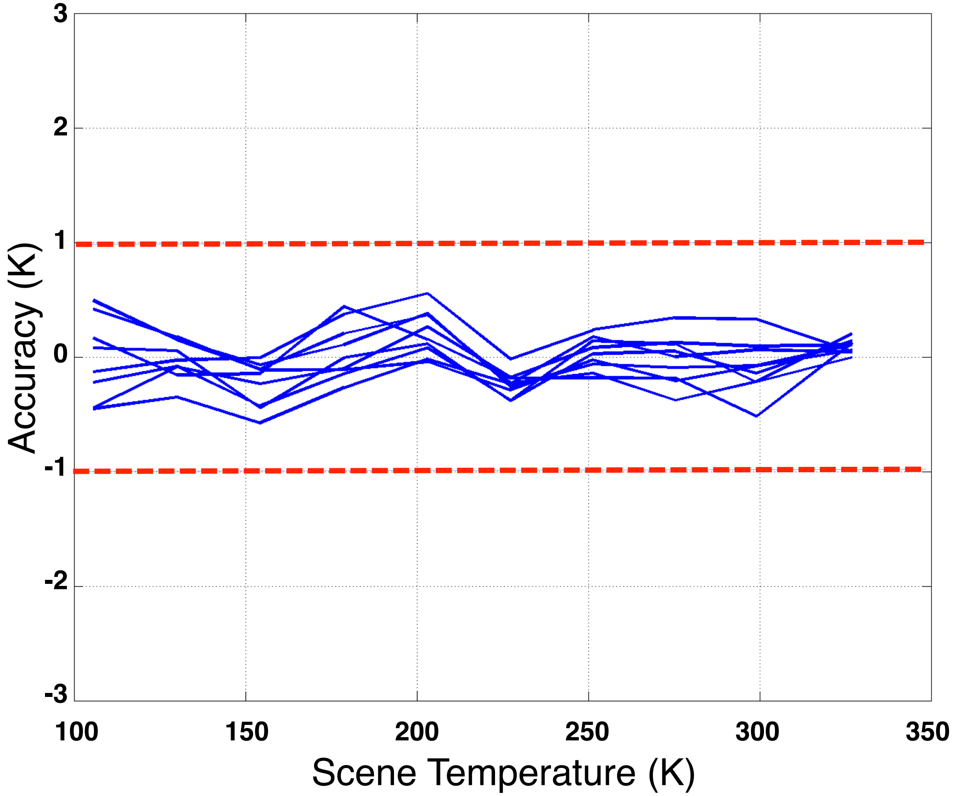
10x10x10 cm, <1 kg, <2 W

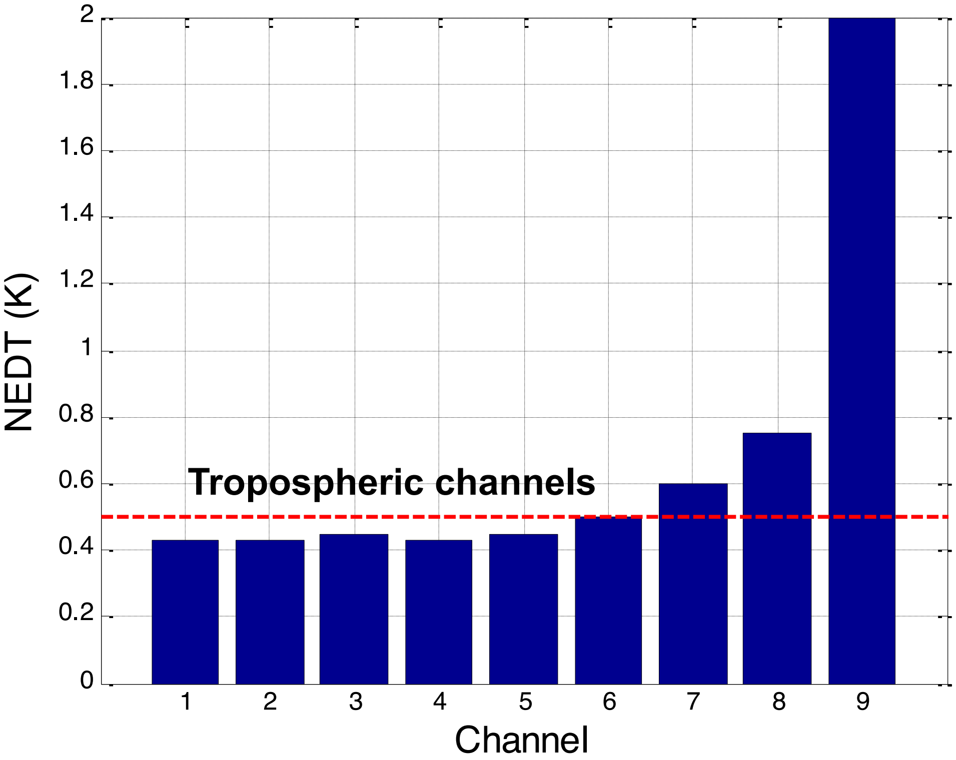
Approximately a factor of 100 reduction in size, weight, and power relative to the current state of the art

MicroMAS Flight Unit



Radiometer Performance (Accuracy and Precision) is State-of-the-ART

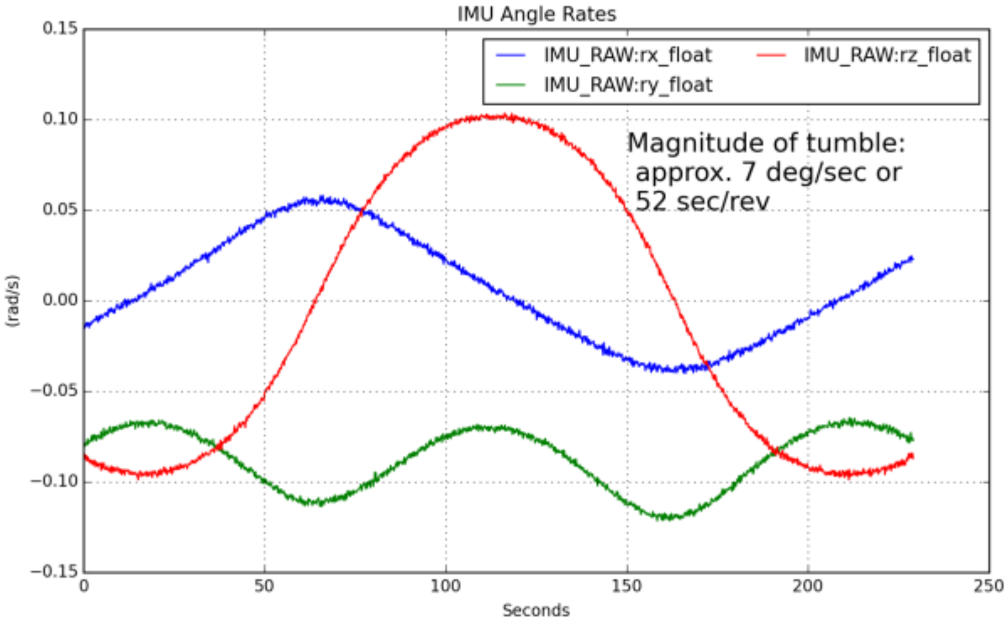


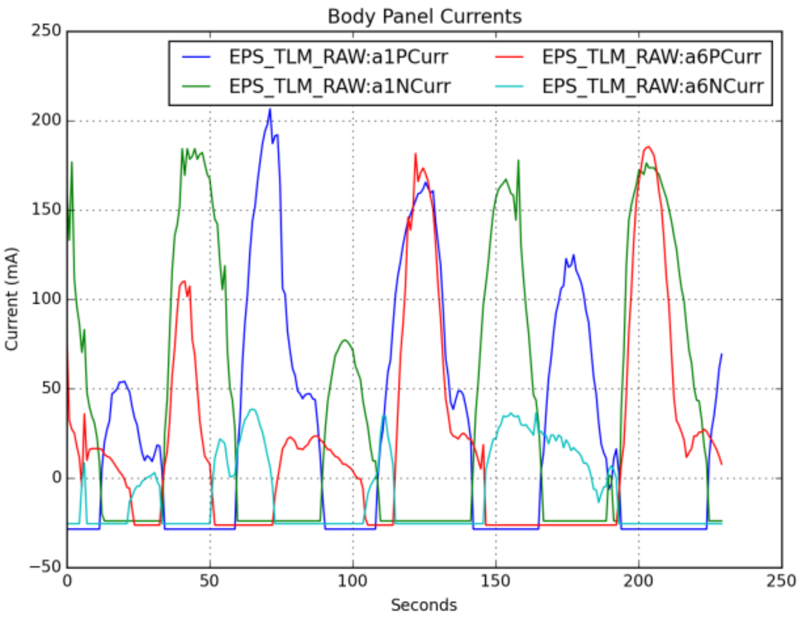


ATMS equivalent spot size; 250 K payload temperature

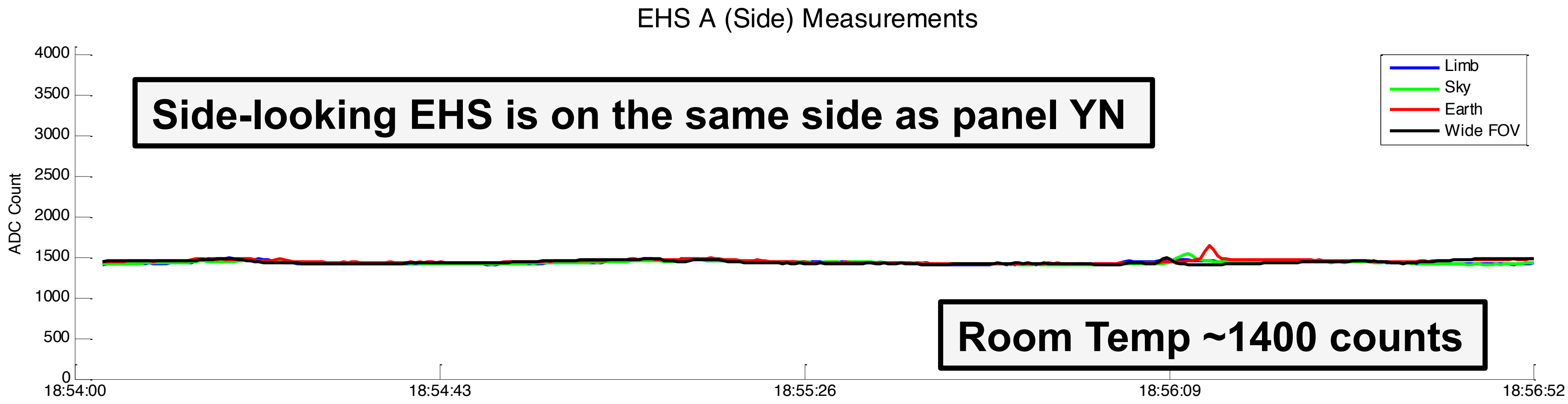
MicroMAS Spacecraft Telemetry

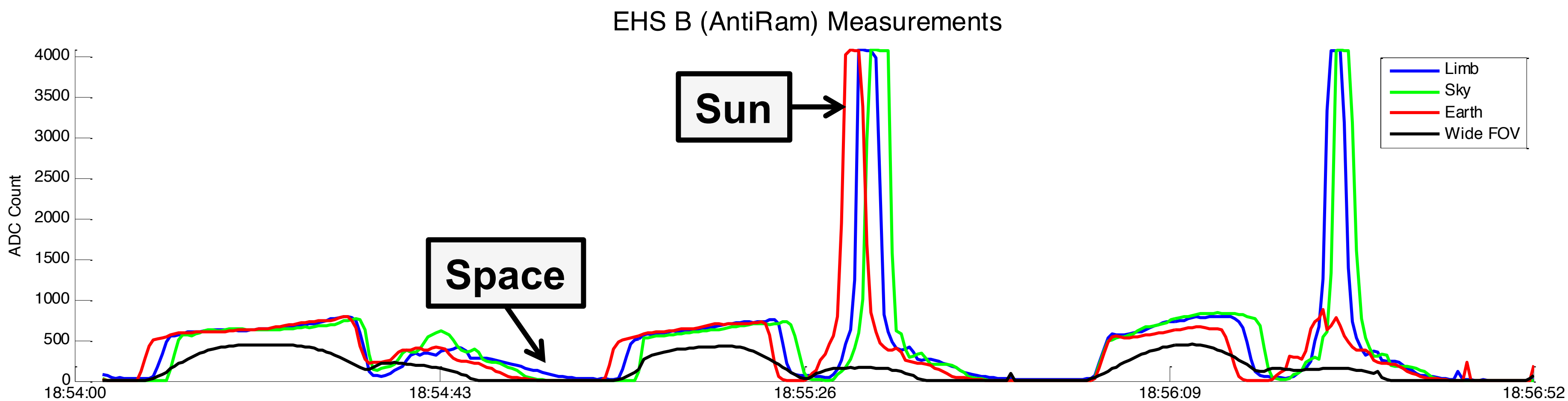
Successful Checkout of Avionics, Power, Attitude Determination, Thermal, and Communications Subsystems



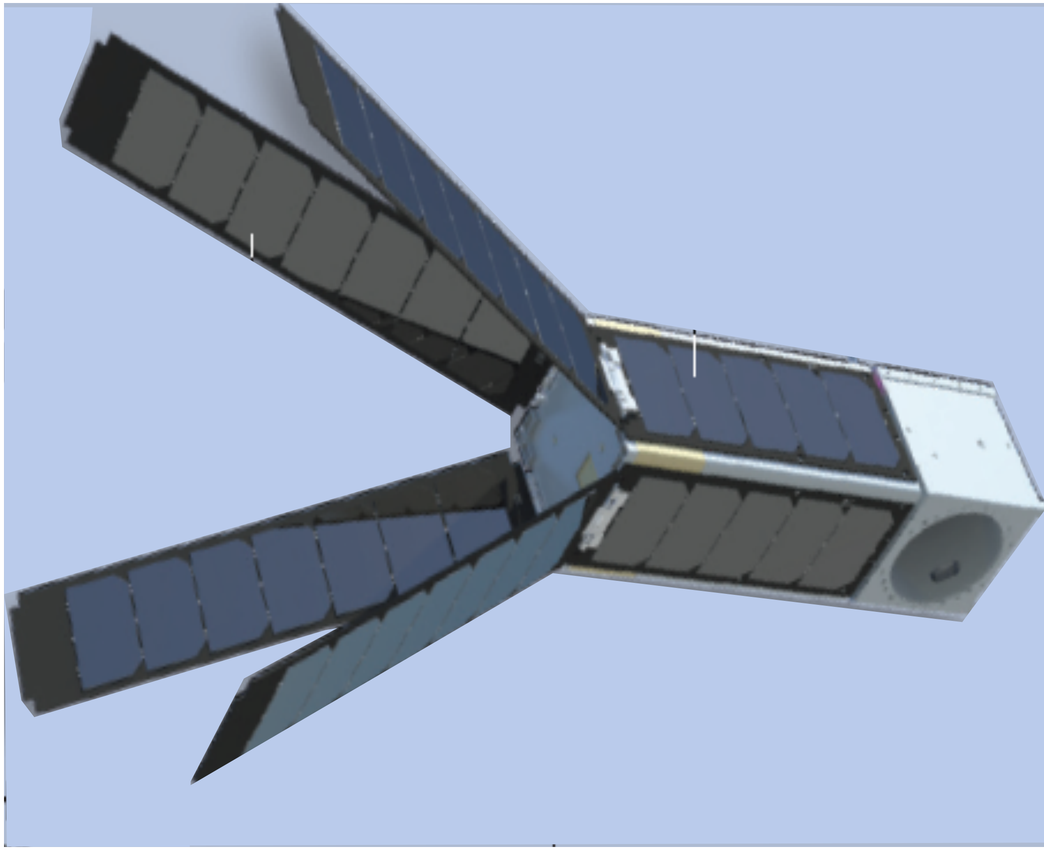


Earth Horizon Sensor Readings





MicroMAS-2
Late 2016 Launch



Spacecraft

- 3.8 kg total mass
- 9.1 W avg power
- 16 kbps max data rate
- 0.2° pointing accuracy

Payload

- 12 Channel (90-206 GHz)
- Scanning Radiometer
- Payload Cube (30 RPM)
- <3 W avg power

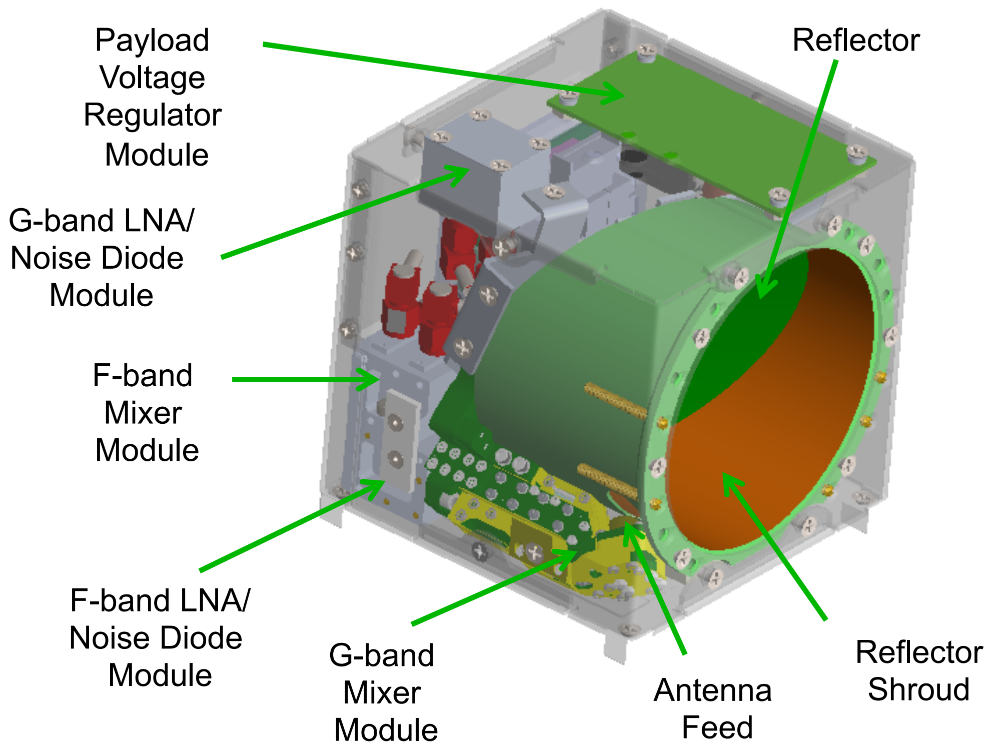
MicroMAS-2 Design Changes

Subsystem	Delta from MicroMAS1		Impact
Payload	Next gen payload 12 channel, quad-band	Better science	Power, Data +~25%
Avionics	More flexible executive code Bug fixes in ADCS code		Improved performance and stability
Comm	-Next gen Cadet high-rate radio -Backup low-rate radio on motherboard (MB)	Backup for Cadet radio failure - Recover ADCS anomaly - Partial data option - Use as beacon	Improved reliability
Power	4@ 3U panels, Deploy to 135°	Supplies more power	Better performance
Launch	ISRO PSLV ISIS Quad pack	Schedule availability	Survive higher launch loads
Orbit	~ 500 km, 98° sun synch	Longer orbit life	Operate in different thermal conditions
Ground segment	Beacon Improved ground station code	Better performance and reliability	Beacon freq approval

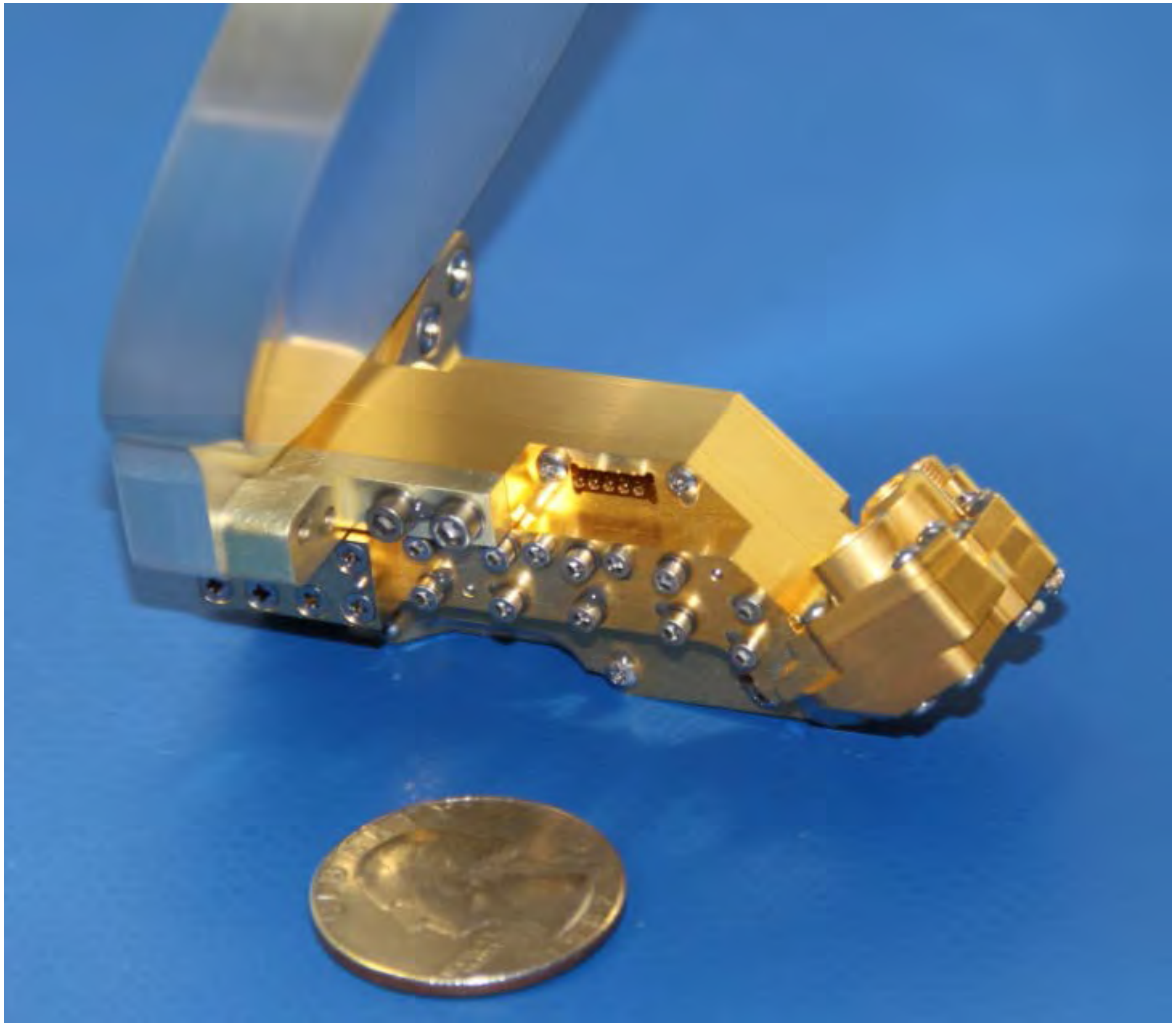
MicroMAS-2 Payload

Ultracompact W/F/G band Radiometer

- Window 2 ch (90, 207 GHz)
- F band 9 ch (115-119 GHz)
- G band 3 ch (183±1, 3, 7 GHz)

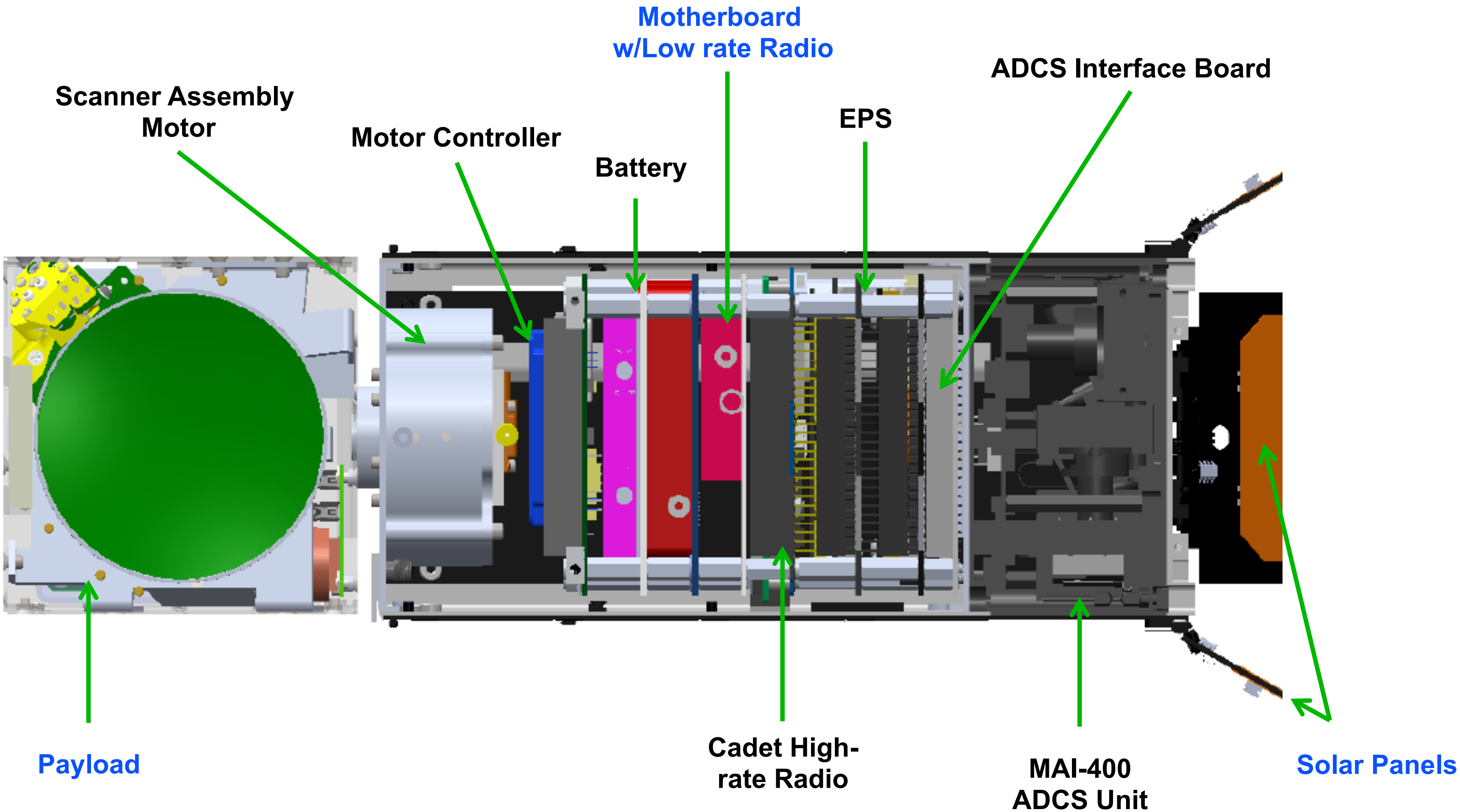


MicroMAS-2 Flight Unit



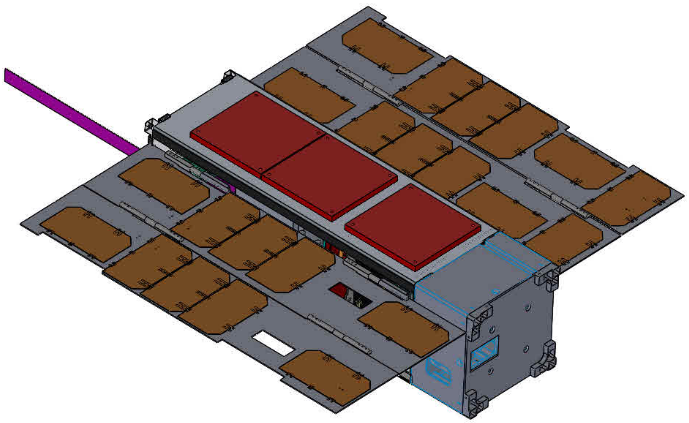
Receiver Temperature
700 K near 183 GHz
2000 K at 207 GHz

Space Vehicle Cutaway



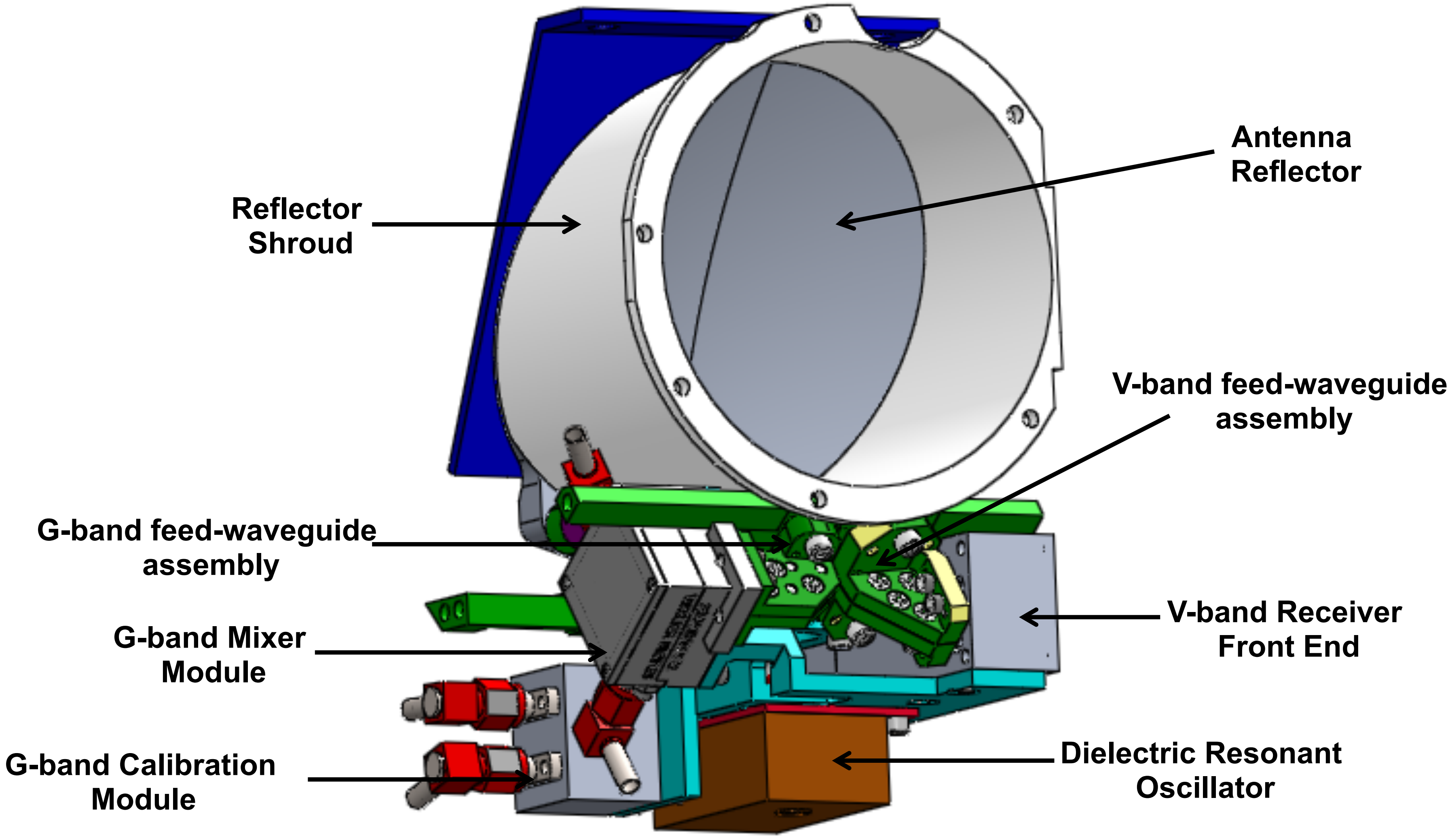
Microwave Radiometer Technology Acceleration (MiRaTA)

- 3U (10 cm x 10 cm x 34 cm) tri-band radiometer
  - Temperature, water vapor, and cloud ice
  - Absolute calibration better than 1 K
- Calibration proof of concept using limb measurements and GPS-RO
  - 60, 183, and 206 GHz; OEM628 GPS
- Funded by NASA Earth Science Technology Office (ESTO)
- $3.6M
- 30-month build (Oct. 2013 – Mar. 2016)
- Launch in late 2016



- 4.5 kg total mass
- 10 W avg power
- 10 kbps max data rate
- 0.5° pointing accuracy

MiRaTA Radiometer System



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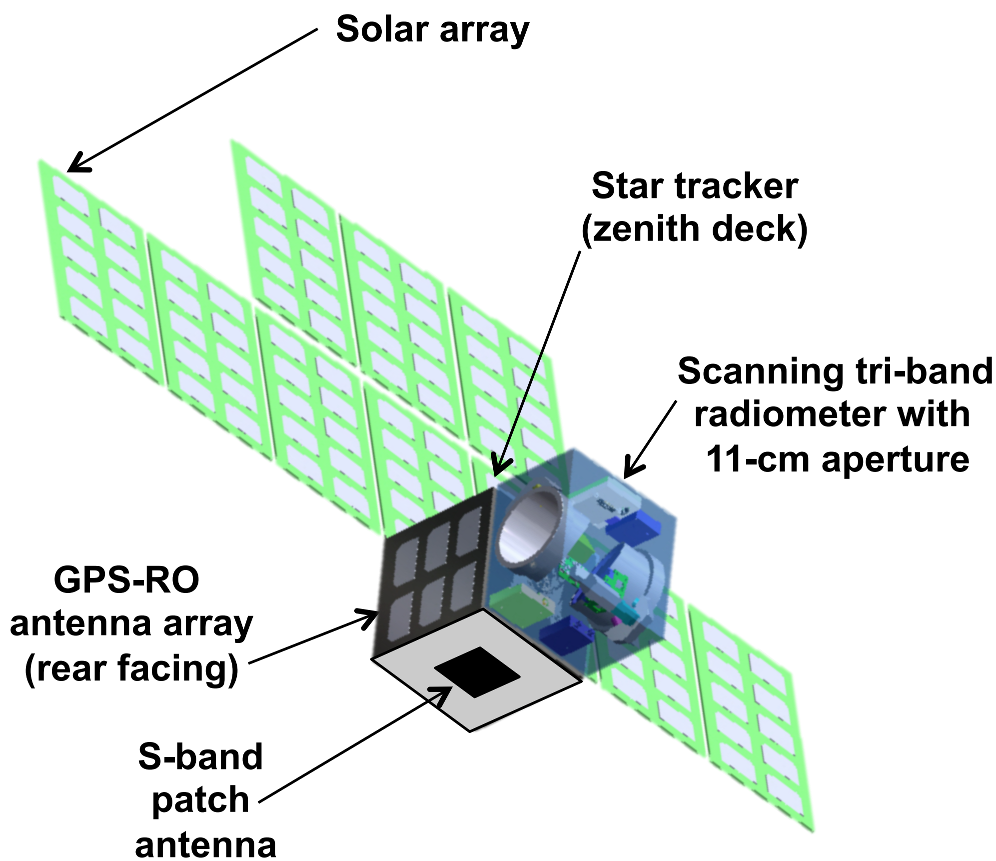
Earth Observing Nanosatellite



EON

<u>Earth Observing Nanosatellite</u>

- All the features of MicroMAS (wide swath) and MiRaTA (sensitivity)
- 12U cubesat (21x21x34 cm)
- Larger aperture (improved spatial resolution)
- 23/31 + 50-60/88 + 166/183 GHz

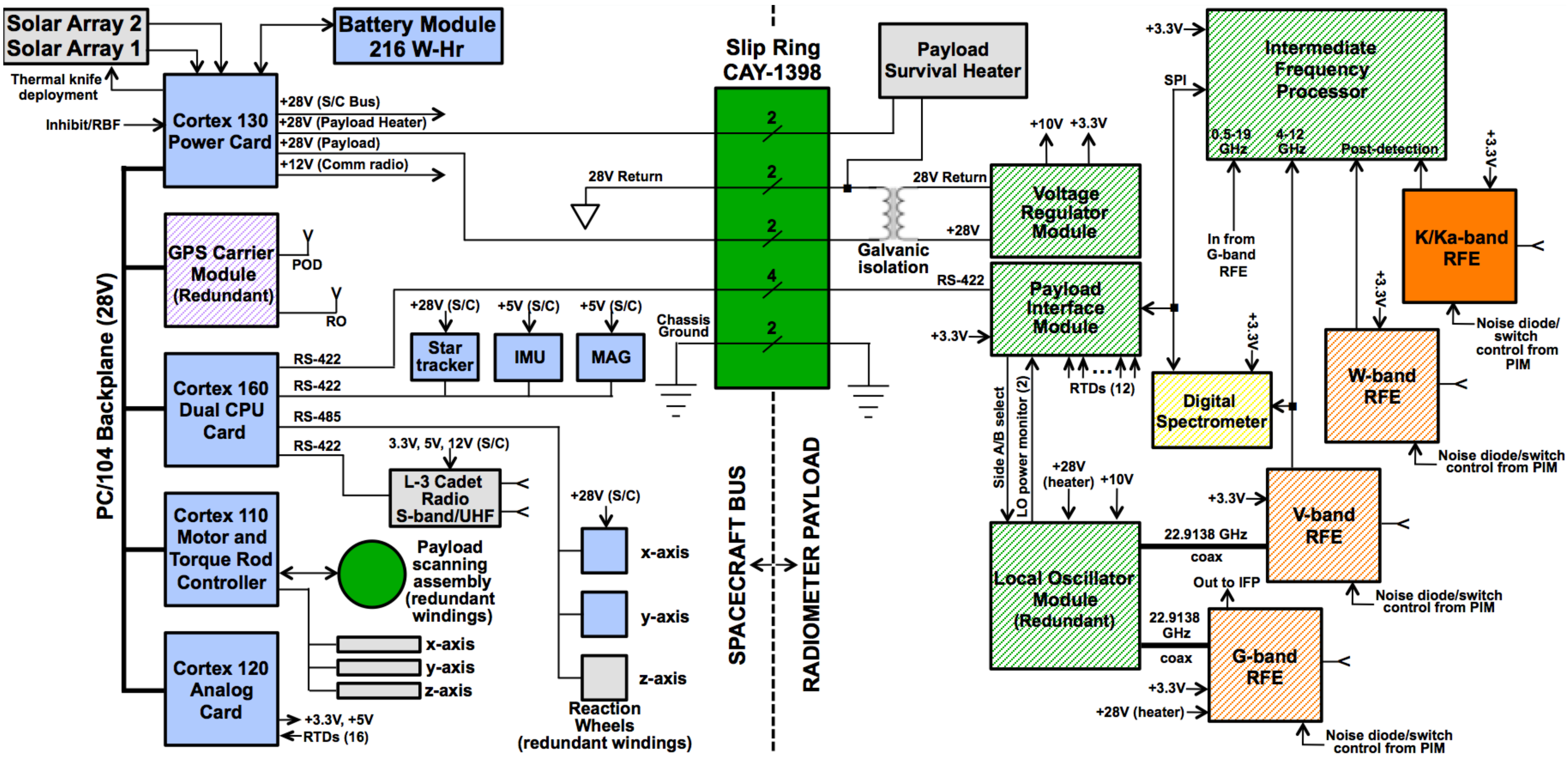
  22 ATMS-equivalent channels
- 2-3 year mission lifetime
- Data downlink using S-band

EON Spacecraft Requirements

- Pointing
  - 0.1-degree (3-sigma) pointing knowledge
  - 0.5-degree (3-sigma) pointing control
  - Expected performance: ~Five times better than requirement
- Power
  - 48 W (avg) power required
  - Solar array to provide 60 W (avg) at end of life (three years)
- Communications
  - Average data rate 50 kbps
  - S-band radio downlinks all data at 100 seconds per orbit
- Lifetime
  - Two years (threshold); >three years (goal)
  - Rad hard/tolerant parts used; TID below 10 krad at three years
  - Scanning assembly lifetime tested to >50M revs (>three years)

EON System Block Diagram & Heritage

MicroMAS | Other | MiRaTA PSSCT-2 TET-1 | MIS/ATMS | SMAP | Other | Modifications



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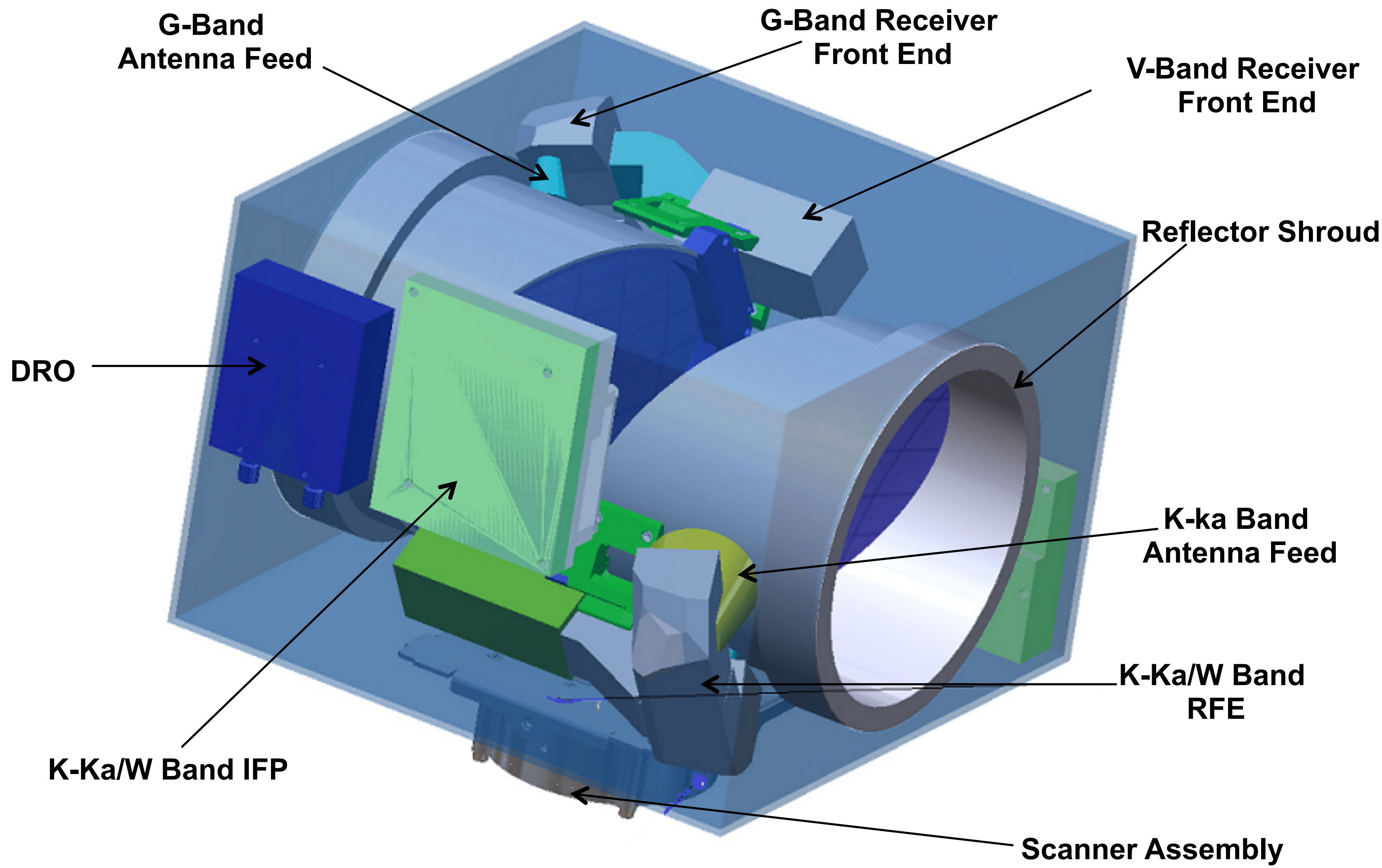
EON Payload


G-Band
Antenna Feed
G-Band Receiver
Front End
V-Band Receiver
Front End
Reflector Shroud
DRO
K-ka Band
Antenna Feed
K-Ka/W Band
RFE
K-Ka/W Band IFP
Scanner Assembly

EON Scanning Assembly Motor

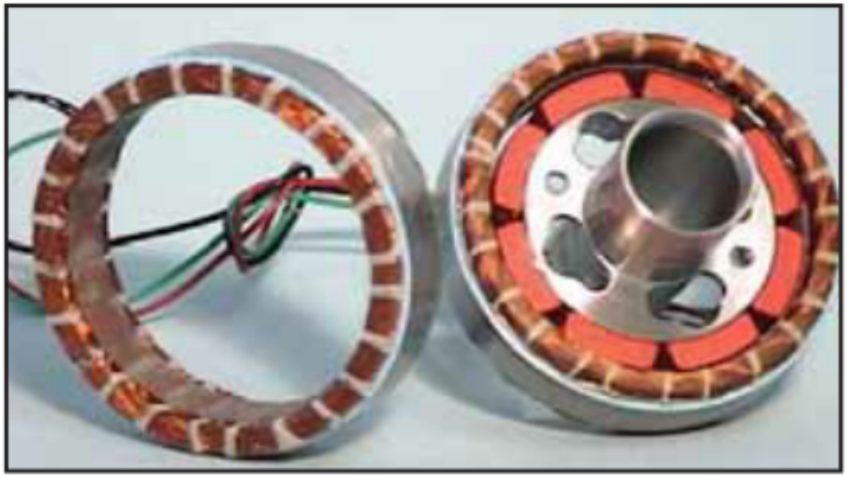


Image courtesy of Aeroflex, Inc

Note: Image of generic Aeroflex BLDC motor

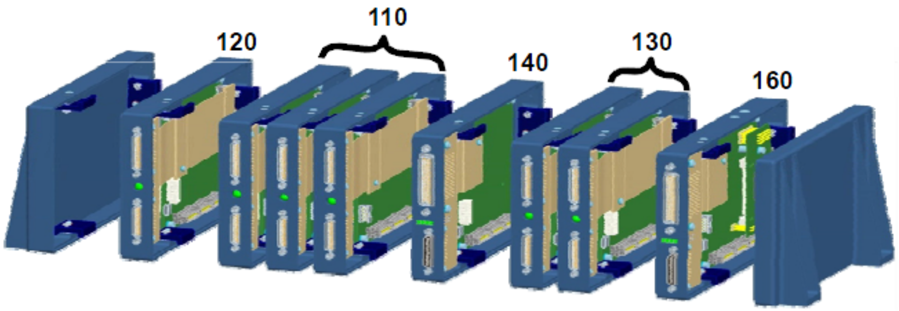
Space Qualified Aeroflex Zero-Cogging Brushless DC Motor

- **Part no: Z-0250-050-3-104**
- **2.5in O.D., 1.5in I.D., 1in height**
- **Mass: 163g**
- **Nominal operating power: 0.020 W**
- **Lifetime tested to >50M rotations (> 3yr EON life)**
- **Redundant windings**

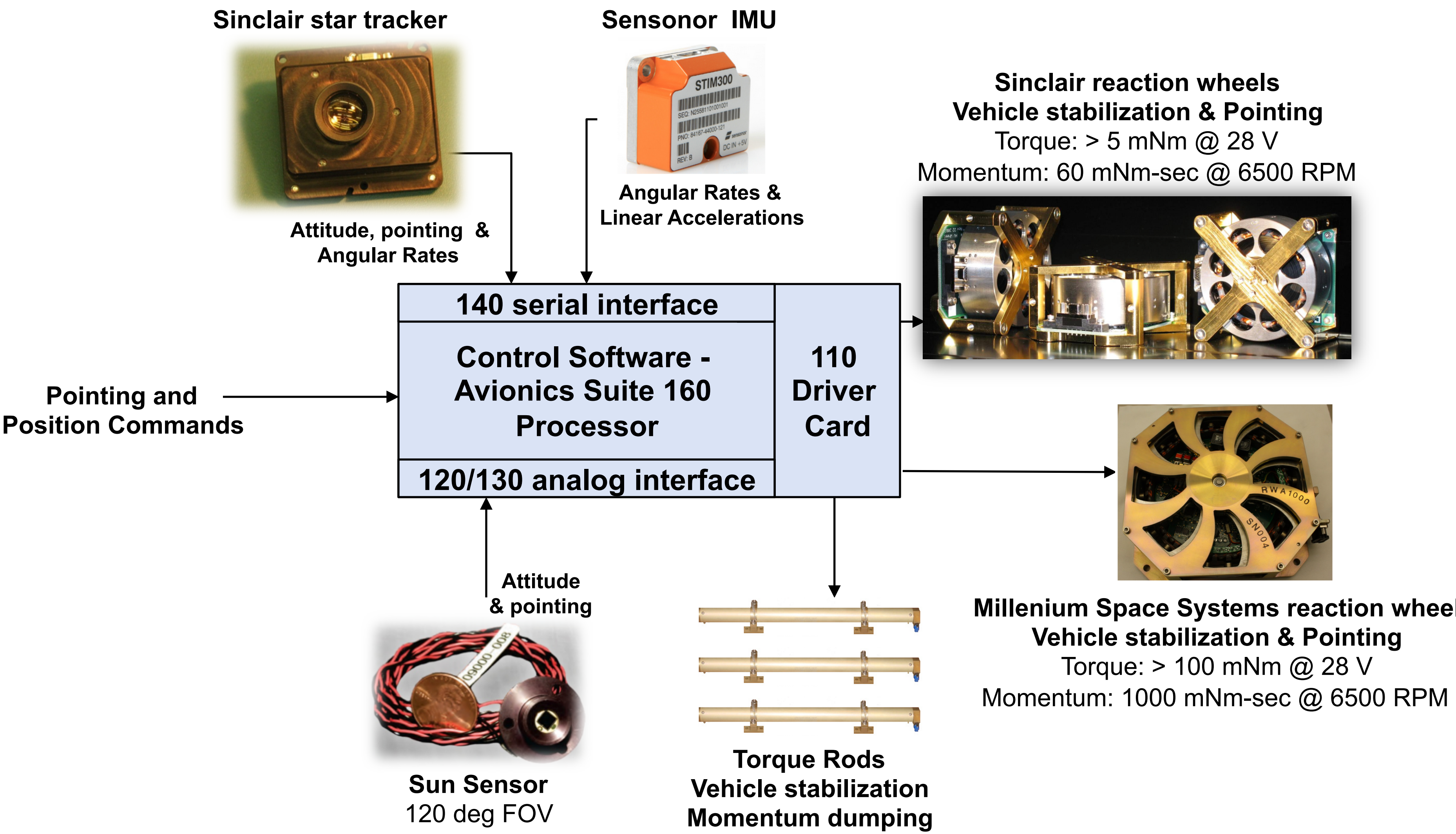
EON Avionics

Andrews Space 100 Series

Model 160 Flight Computer	Processor	Xilinx Virtex 4FX with dual PPC
	Memory	64 MB of SDRAM 2 GB of Flash 1 Mb of EEPROM (x3)
	Operating System	Real Time Linux
Model 140 Communication Card	Supported Interfaces	Ethernet, SPI, I2C, RS-232, RS-422, RS-485, 1553B, JTAG
Model 130 Electrical Power System	Solar Panel Interface	6 Battery Control Regulators Peak Power Tracker
	Battery Interface	7.2 V Lithium Ion
Model 120 Instrumentation Card	A/D Converter	16-bit
	I/O	16 Analog Inputs 2 Analog Outputs 8 Opto-Isolated Digital I/O
Model 110 Motor/Valve Driver Cards	Driver Circuit	36 Channels/ 12 per card (2A/channel)



EON GNC Components



Summary and Path Forward

- **Nanosatellite sounders could provide unprecedented performance at relatively low cost and risk**
- **MicroMAS missions demonstrate core technologies**
- **Pre-launch testing has indicated excellent performance**
  - **40 RPM scanning; 2W payload power consumption**
  - **Accuracy and NEDT meet requirements**
- **MicroMAS-2: Commercially procured launch for Fall 2016**
- **Microwave Radiometer Technology Acceleration (MiRaTA)**
  - **Next generation follow-on with multiple bands (temp. and water)**
  - **2016 launch on JPSS-1**
- **EON-MW could potentially demonstrate ATMS-like quality on a low-cost CubeSat**
  - **If proven, this would be a revolutionary advancement!**

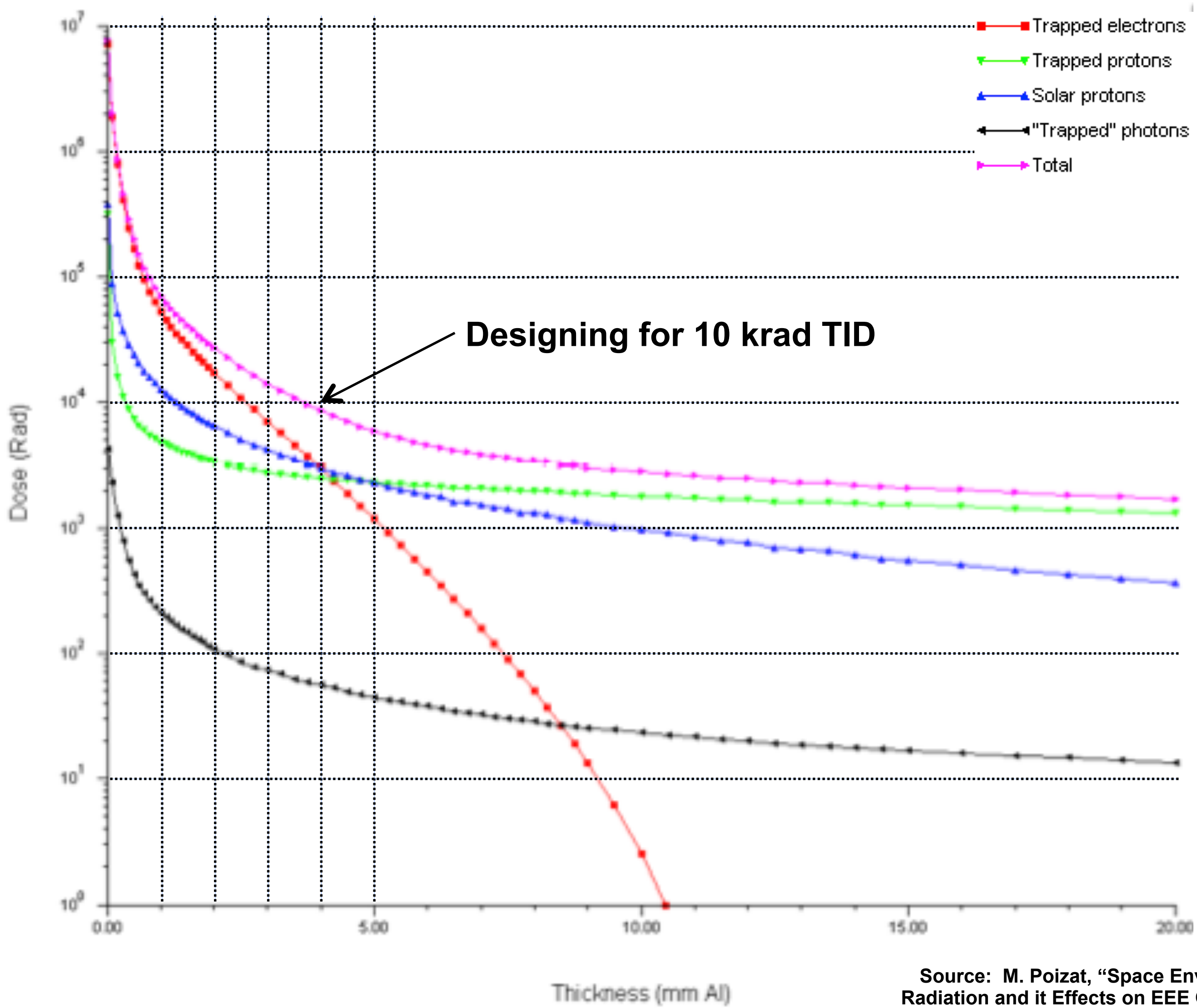
Backup Slides

EON Mass Budget (Mostly Measured Values)

	Mass (kg)
Microwave payload	4
Rotary motor/slipring	0.47
GPS antennas	0.5
Avionics	0.472
Batteries	1.8
Small reaction wheels	0.45
Large wheel	0.97
Torque bars	1
Magnetometer	0.2
Sun Sensor	0.05
Star Tracker	0.085
Deployable solar array	2.45
Structure (Bus)	5
Cables and connectors	1
GPS receiver	0.25
Radio (L-3 Cadet)	0.3
Total	**18.997**

20% Margin (24 kg max)

Dose depth curve for a 5 year LEO polar mission (800km, 98deg)



Source: M. Poizat, "Space Environment and Effects," Space Radiation and it Effects on EEE Components, EPFL June 9, 2009.

EON Payload Power Budget

Component	Power (W)	Duty Cycle (%)	Avg Power (W)
G RFE	2.4	100	2.4
V RFE	1.9	100	1.9
K/Ka RFE	2.125	100	2.125
W RFE	0.375	100	0.375
V Digital	4.375	50	2.188
V PDRO	2.875	100	2.875
Thermal control	6.25	100	6.25
PIM	1.25	100	1.25
IFP	2.8125	100	2.8125
GPSRO	2.5	20	0.5
Total			**22.675**

Power regulation inefficiencies included above.

EON Bus Power Budget

Component	Power (W)	Duty Cycle (%)	Avg Power (W)
Cortex 110	1.3	100	1.3
Cortex 120	1.5	100	1.5
Cortex 130	3.3	100	3.3
Cortex 150	2	100	2
Cortex 160	10	100	10
ST-16	0.5	100	0.5
RW3-0.60	1	100	1
RW3-1.0	2	100	2
Scanning assembly	1	100	1
Comm	10	5	0.5
IMU	1.5	100	1.5
Total			**24.6**

Power regulation inefficiencies included above.

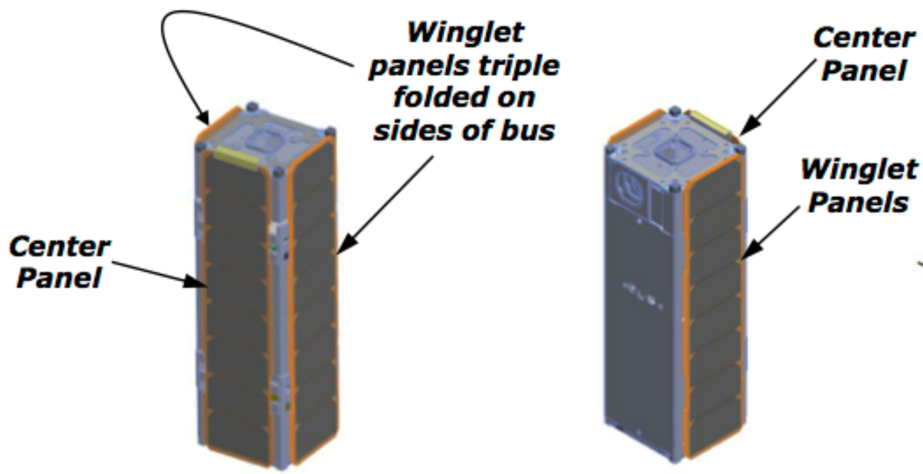
EON Power Budget

- **Payload: 22.7 W**
- **Bus: 24.6 W**
- **Total: 47.3 W**

- **Available from solar array at end-of-life (11:30 orbit): 55 W**

- **Margin: 16 %**

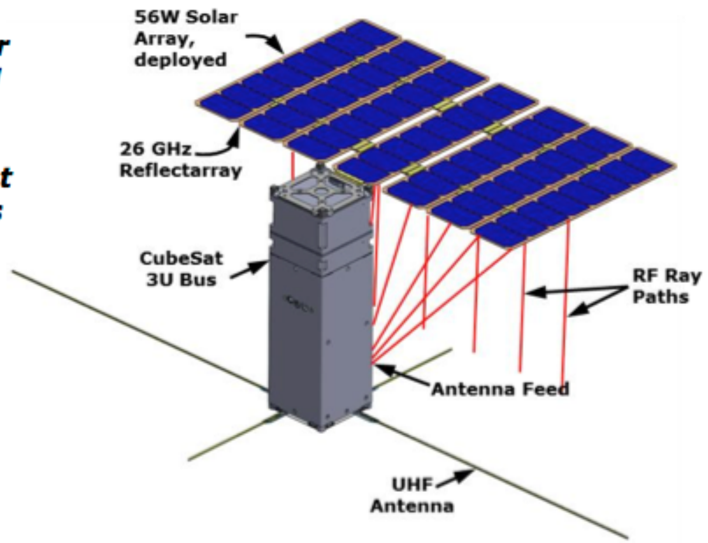
Solar Array Based on ISARA Design Available from Pumpkin, Inc.



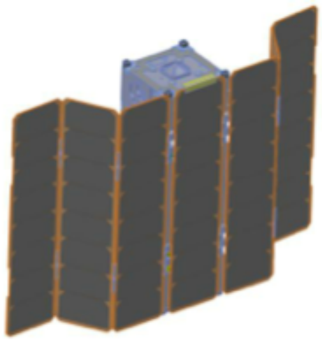
Front View

Back View

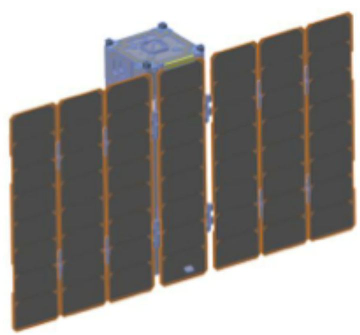
Stowed Configuration



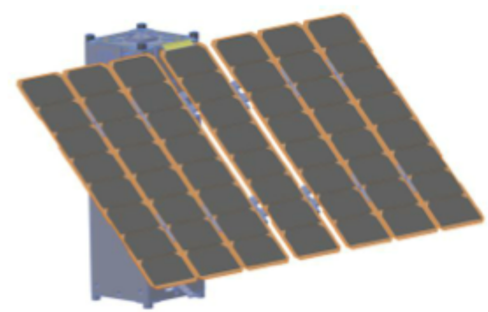
Deployed Configuration



Triple folded side panels flip out



Panels fully unfolded



Solar Array Flips up